Nd:$LiNbO_3$ Microchip Laser with 20GHz Subcarrier

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ABSTRACT

This paper reports on the development of a 20GHz mode-locked Nd:$LiNbO_3$ microchip laser operating at 1.084µm with an output power greater than 35mW (CW). With this configuration, a single device simultaneously generates the optical carrier and the microwave subcarrier. A modulation index of 96% was obtained for a driving microwave power of 12.6dBm at 20GHz. An information signal up to 8GHz was also superimposed on the 20GHz subcarrier using an external modulator.

INTRODUCTION

There is increased need for high speed fiberoptic links operating in the microwave and millimeter wave range with good noise figure and high dynamic range for applications like fiberoptic access to wireless and cable TV [1,2]. Of the different approaches currently investigated [3-5], the mode-locked semiconductor lasers appears to be the most promising. Its principal drawbacks are its inherently high relative intensity noise (RIN) and phase noise, which result in large performance penalties at the system level. Solid state lasers provide high optical power levels, very low RIN and low phase noise, but they are difficult to construct in a compact configuration. This paper explores the possibility of fabricating a small solid state laser which can also provide a microwave subcarrier. The basic concept used here is that a single material can lase and can also be modulated to achive active mode-locking.

Lithium Niobate, one the most commonly used electrooptic crystals due to its excellent optical and electrooptical properties, was established as the prime candidate for this experiment. The lasing properties of Neodymium-doped $LiNbO_3$ were first studied by Evlanova [6], whose initial work was followed by experiments documenting efficient laser operation in this material [7-10]. Therefore, by combining the lasing and electrooptic properties of the Nd:$LiNbO_3$ it is possible to construct a compact actively mode-locked solid-state laser in a microchip configuration.

The optical transmitter under consideration is depicted in Figure 1. The source is a diode pumped microchip laser that produces a stable, low noise optical signal. The length of the cavity determines the free spectral range, or the separation between the axial modes of the laser. If the length of the optical cavity is a few millimeters, then the mode separation will be in the tens of gigahertz. Furthemore, the optical cavity will be resonant in the microwave domain at this frequency.

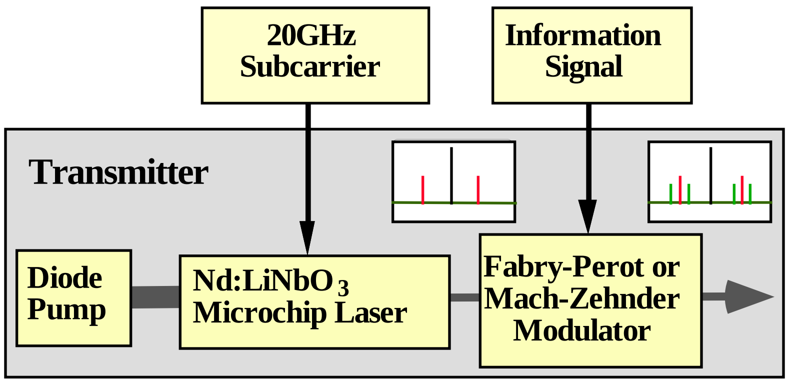

Figure 1 - Block diagram of the microwave modulated optical transmitter under consideration. The Nd:$LiNbO_3$ microchip laser is mode-locked by the 20GHz subcarrier signal. The information signal is then superimposed using an external modulator.

Therefore, when a microwave signal of the appropriate frequency is applied to the device it will effectively couple to the crystal, modulating the electrical/optical length of the cavity. The result is active active mode-locking. The output of the mode-locked laser can be viewed as an optical carrier that is intensity modulated with a large modulation index at the driving frequency.

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Once the optical carrier and microwave subcarrier are generated, the lower frequency information may be superimposed on this signal by an external modulator. This paper concernes with the design, fabrication, and testing of the microchip laser modulated at microwave and millimeter wave frequencies.

FABRICATION

The microchip laser, depicted in Figure 2-(a) uses a y-cut Lithium Niobate ($LiNbO_3$) crystal as host material, doped with 0.44-mole % of Neodymium (Nd). Lithium Niobate is desired since it has excellent optical and electrooptical properties, particularly at large electrooptic coefficient. Neodymium is added to the crystal to provide for lasing at 1.084µm wavelength. Dielectric mirrors were directly deposited on the crystal surfaces forming the optical cavity. The length of the laser cavity was designed to be 3.48mm, which corresponds to an axial mode spacing of 20GHz and matches the desired millimeter wave subcarrier for this particular experiment.

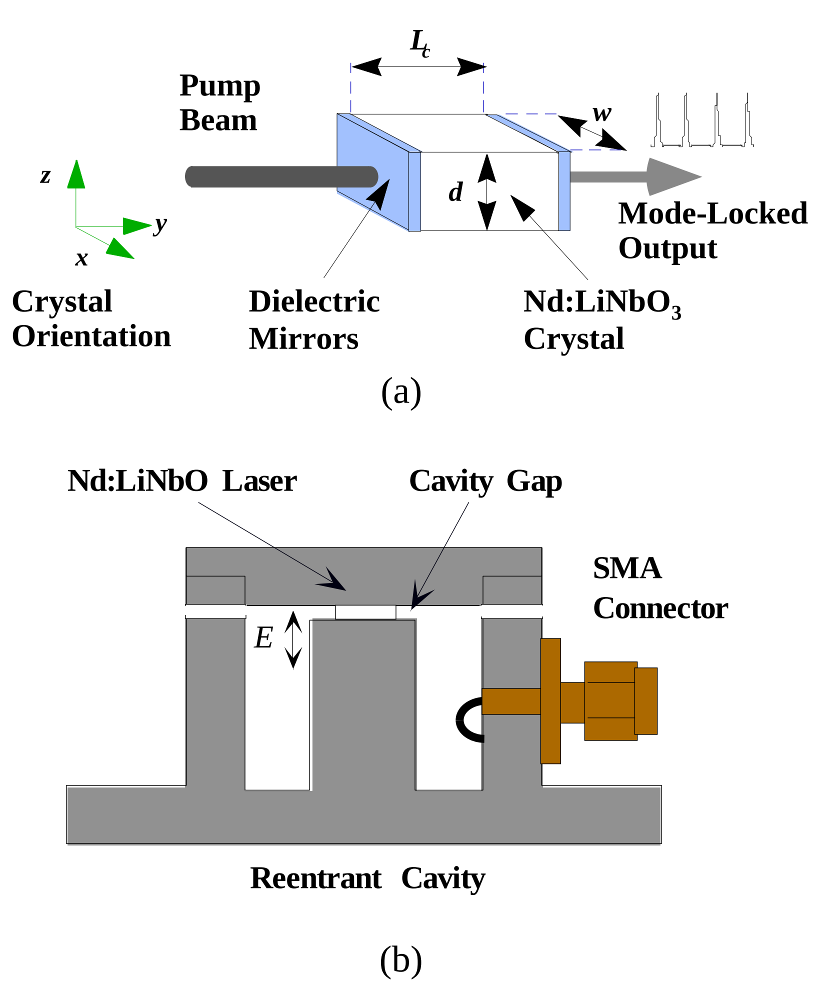


Figure 2 - (a) The mode-locked microchip $Nd:LiNbO_3$ microchip laser. (b) The laser is mounted in the gap of the reentrant microwave cavity where the driving electric field is polarized along the z-axis of the crystal.

The laser is mounted in the gap of a reentrant microwave cavity, shown in Figure 2-(b), where most of the electric field is concentrated [11], and the driving field is applied along the z axis in order to effectively interact with the crystal. The reentrant microwave cavity was designed to be resonant at 20 and 40GHz. The pump beam from a laser diode (Opto Power model OPC-A003) operating at 814nm was collimated and then coupled to the $Nd:LiNbO_3$ laser using free-space optics. A maximum optical output of 35mW was obtained for an estimated absorbed pump power of 200mW, indicating a conversion efficiency around 17.5%

EXPERIMENT

The laser was characterized in the optical, time, and microwave domains. The optical spectrum of the laser was measured using a scanning Fabry-Perot interferometer with a resolution of 0.039nm (i.e. 10GHz) at 1.084µm. The result, shown in Figure 3, reveals a very stable and defined structure, with a Lorentzian-like distribution. The amplitude of the modes, which are 20GHz apart, tend to equalize, indicating that the longitudinal modes are locked. Other measurements revealed that the optical linewidth is ~30kHz (or ~10^{-6} Å).

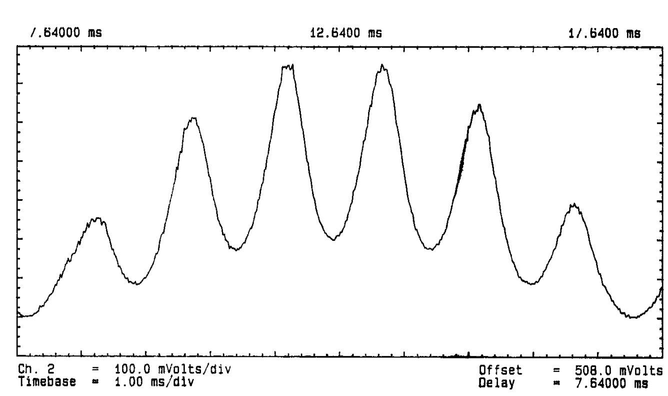


Figure 3 - Measurement of the $Nd:LiNbO_3$ microchip laser spectral intensity using a scanning Fabry-Perot with 0.039nm resolution. Six longituninal modes (20GHz) apart were obtained.

The output beam of the laser was also analyzed in the time domain. The optical signal, detected by the high speed InGaAs Schottky photodiode, was fed into a high frequency sampling oscilloscope (Tektronix model CSA 803). Figure 4 depicts the waveform obtained. The upper trace is the driving signal and the lower trace corresponds to the laser output, which corresponds to a 18.6ps optical pulse. The shape of these pulses is broadened by the bandwidth of the measuring instrumentation which eliminates the higher order harmonics.

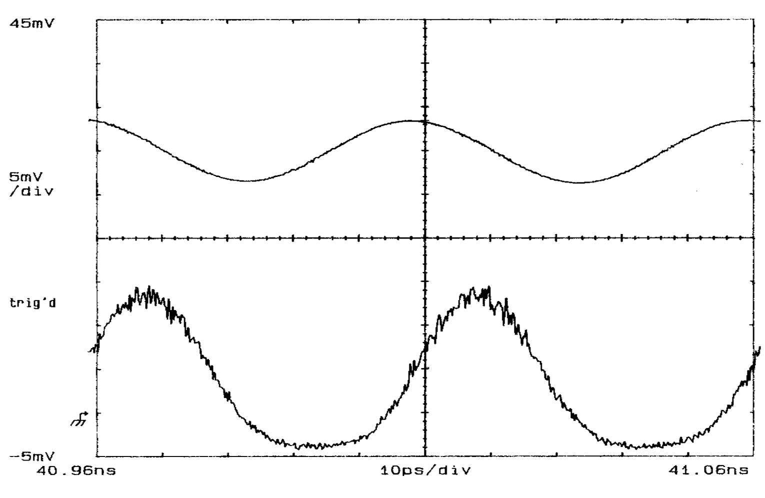
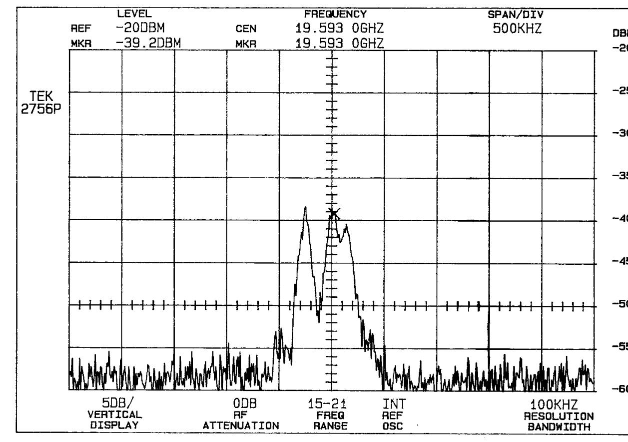


Figure 5 - Time domain measurement of the mode-locked laser output. The vertical scale is 5mV/division and 50mV/division for the lower and upper trace,respectivelly. The horizontal scale is 10ps/division.

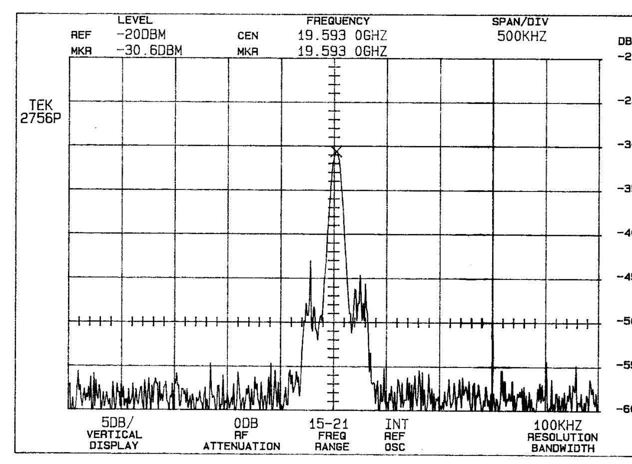
The output signal was also analyzed in the microwave domain. Figure 5(a) shows the 20GHz signal on the microwave spectrum analyzer in the absence of the applied microwave field (free-running laser). Although there is evidence of self mode-locking, the spectrum is unstable and does not have a well defined structure. With a 12.6dBm microwave signal applied to the microwave cavity the signal becomes very stable and an 8.6dB increase of the peak output at 20GHz is noted, as shown in Figure 5(b). The minimum microwave power at which mode locking was obtained was 6 dBm.

The modulation index, which describes the amount of microwave envelope impressed on the optical carrier, was determined by comparing the 20GHz component of the optical signal with the average optical power at the high speed photodetector. A maximum of 96% modulation index was measured for a 12.6dBm microwave power.

The output of the mode-locked microchip laser with the 20GHz modulation envelope was fed into a Mach-Zehnder external modulator to superimpose the information signal. Figure 6 depicts the spectrum of the 20GHz subcarrier and the 40MHz sidebands using a 8GHz Mach-Zehnder modulator.



(a)



(b)

Figure 5 - Microwave spectrum intensities of the laser output for the (a) free-running and (b) mode-locked operation. The vertical scale is 5dB/division, the horizontal scale is 500KHz/division, and the resolution bandwidth is 100KHz.

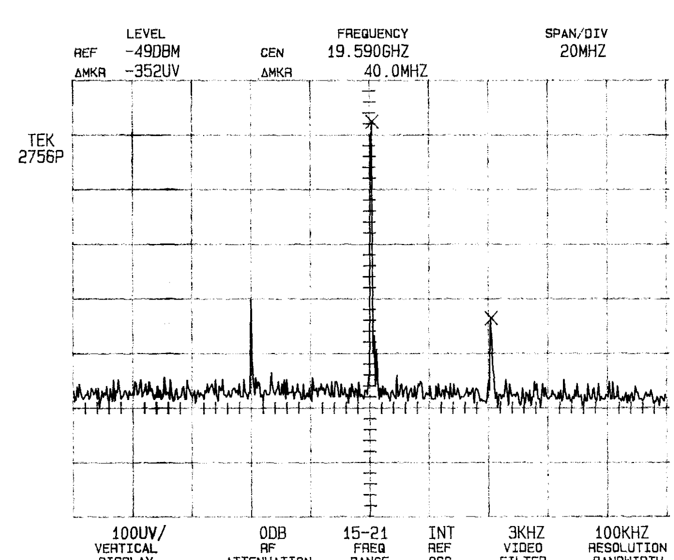


Figure 6 - Spectrum of the 20GHz subcarrier with 40MHz information signal superimposed on the optical carrier. The vertical and horizontal scales are 100uV/division and 20MHz/division, respectively, and the resolution bandwidth is 100KHz.

CONCLUSIONS

The operation of a mode-locked Nd:LiNbO3 microchip laser operating at 20GHz and 35mW output power was demonstrated. A modulation index of 96% was obtained for 12.6 dBm microwave power.

It is important to note that this technique can be extended to higher frequencies by properly scaling the dimensions of the laser and the reentrant cavity. In fact, our models predict that the laser should work as well or better at frequencies up to 100 GHz or higher.

Preliminary results were obtained operating the microchip laser at 40GHz which corresponds to the second harmonic of the cavity. Other doping materails have been also considered in order to obtain laser operation in other wavelengths.

ACKNOWLEDGEMENTS

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REFERENCES

[1] H. Ogawa, D. Polifko, and S. Banba, “Millimeter-wave fiber optic systems for personal radio communication,” IEEE Trans. Microwave Theory Tech., vol. MTT-40, no. 5, pp. 2285-2292, May, 1992.

[2] D. Wake, C. R. Lima, P.A. Davies, “Optical Generation of Millimeter-Wave Signals for Fiber-Radio Systems Using a Dual-Mode DFB Semiconductor Laser,” IEEE Trans. Microwave Theory Tech., Vol. 43, No. 9, pp. 2270-2276, September, 1995.

[3] D. J. Derickson, R. J. Helkey, A. Mar, “Microwave and Millimeter Wave Signal Generation Using Mode-Locked Semiconductor Lasers with Intra-Waveguide Saturable Absorbers," 1992 IEEE MTT-S Digest, pp. 753-756, Albuquerque, 1992.

[4] Z. Ahmed et al., “Millimeter-wave (37GHz) Transmission Data (up to 500Mb/s) in an Optically Fed Wireless Link Incorporating a Hybrid Mode-Locked Monolithic DBR Laser,” International Topical Meeting on Microwave Photonics, pp. 45-48, Kyoto, Japan, 1996.

[5] D. Novak, C. Lim, H. F. Liu, “Optimization of Millimeter-Wave Signal Generation Using Multi-Electrode Semiconductor Lasers with Subharmonic Electrical Injection,” International Topical Meeting on Microwave Photonics, pp. 85-88, Kyoto, Japan, 1996.

[6] N. F. Evlanova et al., “Stimulated Emission of $LiNbO_3$ crystals with Neodymium Impurity,” JETP Letters, Vol. 5, No. 10, pp. 291-292, 1967.

[7] I. P. Kaminow and L. W. Stulz, “Nd:$LiNbO_3$ Laser,” IEEE Jounal of Quantum Electronics, Vol. , No. , pp. 306-308, June, 1975.

[8] Eric Lallier, “Rare-earth-doped glass and $LiNbO_3$ waveguide lasers and optical amplifiers,” Applied Optics, Vol. 31, No. 25, pp. 5276-5282, September, 1992.

[9] T. Y. Fan et al., “Nd:MgO:$LiNbO_3$ spectroscopy and laser devices,” J. Opt. Soc. Am. B, Vol. 3, No.1, January 1986, pp. 140-147.

[10] A. Cordova-Plaza et al., “Nd:MgO:$LiNbO_3$ continuous-wave laser pumped by a laser diode,” Optics Letters, Vol. 13, No. 3, March 1988, pp. 209-211.

[11] O. P. Gandhi, "Microwave Engineering and Applications," Pergamon Press, New York, 1981.